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The following individual reports were prepared by the Assistant Research Scientists on the project.

Joseph S. Hogan

ATMOSPHERE OF MARS

Work on the extension of the calculations of Prabhakara and Hogan (1965A) to higher levels of the Martian atmosphere was continued and the following steps were completed.

An investigation was undertaken to determine the effect of refinement of the spectral intervals in the 15μ CO_2 band on the calculations. The 15μ CO_2 band is the dominant one for radiative transfer in the lower Martian atmosphere. The strong region of the band (700 cm^{-1} to 600 cm^{-1}) was divided first into two 50 cm^{-1} wavenumber intervals, then into five 20 cm^{-1} wavenumber intervals. For each case an equilibrium structure was obtained for the Earth's atmosphere below 100 km. The two temperature profiles which resulted differed by, at most, 3°K throughout the region of the atmosphere for which the calculations were performed, and both were in excellent agreement with normally observed atmospheric temperature profiles. It was therefore deemed quite acceptable to use the broader spectral intervals in further Earth or Mars calculations in the interest of economy of computer time.

A numerical procedure was developed to take the Doppler broadening of the spectral lines into account in the radiative transfer calculation and in the calculation of the solar near infrared energy (1μ to 6μ) absorbed by CO_2 in the Martian atmosphere. A method was also developed for taking into account the variation of the Doppler half width with temperature and frequency in these calculations.

The effects of vibrational relaxation in the 15μ CO_2 band on the structure of the Martian atmosphere was included in the calculations using the same techniques employed by Prabhakara and Hogan (1965B) in their study of the mesopause region of the Earth's atmosphere.

The model Martian atmosphere was extended to about 200 km and an investigation was made to determine the effect of layer thicknesses on the equilibrium structure calculated. The atmosphere was first divided into 50 layers of 2 km thickness extending from the surface to the 100 km level, with 10 layers of 10 km thickness between 100 km and 200 km. The atmosphere was then divided into six groups of 10 equally thick layers, the thickness varying from 1 km near the ground to 6 km near the upper boundary (210 km). The overall equilibrium atmospheric structures proved to be quite similar for the two cases. The latter stratification was adopted, however, since it is more refined in both the lower and upper atmosphere with but a small sacrifice on the layer thickness in the intermediate regions.

Finally, work was begun on a numerical scheme designed to incorporate the equilibrium photochemistry of CO_2 in the presence of solar ultraviolet radiation into this study of the Martian atmosphere.

References

Prabhakara, C., and J. S. Hogan, 1965A: Ozone and carbon dioxide heating in the Martian atmosphere. J. Atm. Sci., v. 22, pp. 97-109.

Prabhakara, C., and J. S. Hogan, 1965B: Equilibrium temperature structure in the mesosphere and lower thermosphere. Goddard Institute for Space Studies, New York.

Joel S. Levine

I. UPPER ATMOSPHERIC SODIUM

In a previous HIAM Project Report (covering the period December, 1964-May 1965, pp. 3-6), methods were discussed for the use of time and space variations of the sodium airglow ($\lambda = 5892$ Å) to study the dynamics and circulation of the mesosphere-lower thermosphere region. Before we can interpret airglow intensity variations in terms of atmospheric dynamics, knowledge of the origin of free upper atmospheric sodium is essential. It has been concluded (Junge, Oldenberg and Wasson, 1962) that atmospheric sodium is extraterrestrial in origin and due to meteoric influx. For several reasons outlined in the previous HIAM Project Report, we have questioned this conclusion, and have examined the sea as a possible source of free atmospheric sodium (sodium chloride sea-salt crystals).

We have considered the possibility of the upward transport of sodium in the form of sodium chloride crystals, as well as the possibility of liberating sodium from the crystal at lower altitudes, and then upward molecular diffusion in the form of free sodium or in sodium-oxygen compounds.

To break the sodium chloride crystal into gaseous ions of sodium and chlorine we need about 7.88 ev, which corresponds to about 1590 Å. Once the sodium ion is liberated it can easily combine with an atmospheric electron forming a free sodium atom. In the 1100-1350 Å region, absorption varies greatly with wavelength, with certain narrow bands penetrating down to 50 km. It is conceivable that some sodium can be liberated by this process. Once the sodium atom is free to combine with oxygen the picture becomes more complicated. A literature search failed to yield any quantitative data on photo-dissociation reactions of sodium-oxygen compounds. We just do not know much about the chemistry and photo-chemistry of sodium-oxide reactions, which is essential in order to trace the path of a sodium atom through the atmosphere.

If the sea is the source of atmospheric sodium, we can easily get appreciable amounts of the sodium chloride crystal through the troposphere because of strong vertical motions within this region. However, through the tropopause-stratosphere region the mixing ratio of the sodium chloride crystal decreases rapidly. Three possible mechanisms to get appreciable amounts of sodium chloride crystals through the tropopause-stratosphere region are suggested here: tropopause discontinuities, vertical transport due to the strong motions within the intertropical convergence zone and the "sudden stratospheric warming" phenonenon. The first two suggested transport mechanisms may be latitudinally affected. Hence, we are looking into possible latitudinal variations of the sodium airglow. The difficulty in trying to detect latitudinal variations in the sodium airglow is that different observing stations have different measuring instruments and different calibration techniques. A possible interaction of tropospheric and stratospheric air may occur during the "sudden stratospheric warming" phenomenon. Walker (1965) recently wrote that scientists at Kitt Peak National Observatory, Tucson, Arizona, are looking at their sodium airglow data in the hope of correlating sodium airglow intensity with times of stratospheric warmings. It is our opinion that stratospheric warmings are too localized and too short-lived to account for any appreciable sodium chloride transport through the tropopause-stratosphere region. To date, we have not heard the results, if any, of the Kitt Peak study.

In recent discussions with Dr. J. London, it has been pointed out that if we consider sodium chloride particles at the small end of the particle spectrum (Particle radius $< 1.0\mu$) the effect of downward gravitational sedimentation will be minimized. If the downward sedimentation flux approsimates the upward crystal flux, the assumption of a constant mixing ratio above the tropopause is valid (the upward crystal flux depends strongly on the eddy diffusion coefficient of the lower atmosphere upon whose value there is considerable uncertainty). However, if this assumption is made, Junge's (1962) value for the total amount of free sodium above 70 km for a constant mixing ratio of 6.5×10^{-13} is meaningful when compared to the value of 10^{-2} of sodium which is suggested by airglow observations. This value for the constant mixing ratio approximation does not include any additional sodium contribution from crystal liberation by solar radiation at lower altitudes, as suggested earlier in this report.

Preliminary results from NASA's Pegasus micro-meteoroid detection satellites suggest that extraterrestrial meteor influx is not as great as believed in pre-Pegasus days (Pegasus 1 was launched on February 16, 1965; Pegasus 2 on May 25 and Pegasus 3 on July 30, 1965). It is interesting to note that a study by Dr. W. Hartman reported in Sky and Telescope (vol. 30, no. 6, p. 352, December 1965) concludes that the influx of meteoric material reaching the planets has decreased with time during the life of the solar system.

In light of the following points made in this study, including:

1. Verticle distribution of sodium based on steady-state equilibrium calculations (see last Hiam report, pp 3-6),
2. The possibility of sodium liberation from the sodium chloride crystal by solar radiation,
3. The constant mixing ratio approximation, and
4. The possibility that meteoric particle influx may be smaller than previously thought,

we believe that Junge's (1962) conclusion that upper atmospheric sodium is extraterrestrial in origin must be re-examined quantitatively when the Pegasus meteor influx data is published. We further believe that the sea cannot be discounted as a source of atmospheric sodium—illustrating still another air-sea interaction on our water-covered planet.

Before his departure for Kitt Peak National Observatory, Dr. James C. G. Walker, Research Associate at the Goddard Institute for Space Studies, NASA, assisted on this project. Several discussions with Drs. A. Arking and S. I. Rasool, Adjunct Associate Professors of Meteorology at New York University and Research Associates at the Goddard Institute also proved helpful.

II. THE ASHEN LIGHT ON VENUS

There has been recent interest in the nature of the dark-side portion of the atmosphere of Venus, in regard to the origin and emission of thermal radiation (Murray and Westphal, 1965; Strong, 1965). Another interesting dark-side phenomenon on Venus is the occasional occurrence of a faint luminous glow known as the "ashen light". The state of knowledge of the ashen light is summed up nicely in the following sentence: "so far, the observations of the light are too few, too scattered, and too uncertain for proper analysis" (Moore, 1959).

During the summer, with the assistance of Messrs. Jerry McCaffrey and Robert Michalove*, a search of astronomical and observing periodicals netted a total of

*High school students taking part in a research experience program at New York University.

forty-nine independent observations of this atmospheric phenomenon on Venus between 1959 and 1962.

We are currently examining our observations in an effort to determine something about the origin and nature of this glow. It has been suggested that the ashen light on Venus is analogous to our terrestrial auroral or airglow atmospheric radiation. If it is actually an auroral or airglow phenomenon within the atmosphere, it may be an important energy sink in determining the net energy balance of Venus.

In order to analyze the observations, we determined the earth-sun-Venus reference angle for all occurrences (a reference angle of 0° corresponds to inferior conjunction with Venus directly between the Sun and Earth; an angle of 180° corresponds to superior conjunction with the Sun directly between Earth and Venus). During times near inferior conjunction, Venus shows an almost completely non-illuminated face, while during the time near superior conjunction Venus is almost completely illuminated. It has always been assumed among astronomical observers that the frequency of the ashen light phenomenon increased as the area of the non-illuminated side of the planet increased, since there would be a greater dark background to observe this faint glow against. However, our study shows that there is no preferred illumination or reference angle for the glow to occur, as shown in the following table:

Number of ashen light occurrences, 1959-1962, divided into 10° Earth-Sun-Venus reference angle intervals

1-10°	11-20°	21-30°	31-40°
5 occurrences	6 occurrences	6 occurrences	8 occurrences
41-50°	51-60°	61-70°	71-80°
8 occurrences	7 occurrences	5 occurrences	4 occurrences

Our study shows an apparent independence of the ashen light occurrence on Venus with respect to the position of the earth and the sun. In an effort to determine something about the origin mechanism of the glow, we will try to correlate glow occurrences with the following parameters: solar activity (sunspot number, solar flares, coronal changes), variations in the speed and density of the solar wind (solar plasma), terrestrial auroral and airglow activity, as well as variations in the general geomagnetic field.

References

Junge, C. E., O. Oldenberg, and J. T. Wasson, 1962: On the origin of the sodium present in the upper atmosphere. J. Geophys. Res., 67, pp. 1027-1039.

Moore, P., 1959: The Planet Venus. MacMillan, New York, p. 99.

Murray, B. C. and J. A. Westphal, 1965: Infra-red astronomy. Scientific American, v. 213, no. 2, pp. 20-29.

Strong, J. D. 1965: Telescopic observations of planet Venus from balloons. Conference on Mars and Venus, Virginia Polytechnic Institute, Blacksburg, Va., 23 August 1965.

Walker, J. C. G., 1965: (Personal communication from Kitt Peak National Observation).

Wayne E. McGovern

I. ROTATION PERIOD OF THE PLANET MERCURY

During the inferior conjunction of Mercury in April 1965, Pettengill and Dyce (1965) made radar observations of the planet and derived a value for the rotation period of 59 ± 5 days.

This result was in disagreement with the previously accepted value of 88 days, as first reported by Schiaparelli (1882) and subsequently confirmed by Lyot (1943) and Dollfus (1961). This conclusion was primarily based upon visual observations of the planet which indicated re-occurrence of surface markings, even over long intervals of time. The conclusion was further substantiated by the theoretical argument that because of nearness of Mercury to the Sun the solar tidal force would be so strong that the planet would be "locked" in the direction of the sun as the moon is with respect to the Earth.

An investigation into the reasons for this apparent inconsistency was carried out in collaboration with Drs. S. I. Rasool and S. H. Gross of the Goddard Institute for Space Studies.

We examined many drawings of Mercury intermittently made over the past seventy years. Of these, six pairs of drawings showed near duplication of markings and phase.

Duplication of markings and phase for any single pair of drawings of Mercury does not necessarily indicate that synchronous rotation of the planet is the only possible solution. A number of other periods are possible, and these were calculated for each pair of drawings. However, only one of these values (58.4 ± 0.4) was common to all pairs of drawings and within the allowed limits of 59 ± 5 days as determined by radar.

Therefore, this study produced an improvement in the determination of the period of Mercury, in addition to showing the consistency between both the visual and the radar observations.

This work was published in Nature, v. 208, p. 375, 1965, "The rotation period of the planet Mercury".

II. THE ATMOSPHERE OF MERCURY

An extension of the work outlined in the previous report (Dec. 1964-May 1965) concerning the atmosphere of Mercury is nearing completion. The final report will include a study into the evidence for the presence of an atmosphere on Mercury. In addition, dissipative effects on the atmosphere have been examined, particularly solar wind and thermal escape of gases from the gravitational field of the planet. From consideration of the solar wind a lower limit of Mercury's magnetic field at the surface has been established. In connection with the gravitational escape of gases, improved exospheric temperatures were computed for three composition models, 100% CO_2; 50% CO_2 and 50% Argon; and 50% CO_2 and 50% Neon. These studies indicate that CO is the dominant cooling agent in the upper region of Mercury's atmosphere and appears to be effective in preserving an atmosphere on Mercury. Other areas of investigation were the thermal structure of the lower regions of Mercury's atmosphere.

A paper on this subject, prepared in conjunction with Drs. S. I. Rasool and S. H. Gross, will be submitted to Space Science Reviews for publication.

References

Dollfus, A., 1961: Planets and Satellites, edited by Kuiper, G.P., B. M. Middlehurst. Chicago Univ. Press.

Lyot, B., 1943: Astronomie, v. 67, p. 3.

Pettengill, G. H. and R. B. Dyce, 1965: Nature, v. 206, p. 1240.

Schiaparelli, 1889: Astronomische Nachrichten, v. 123, p. 2944.

Eugene E. A. Chermack

OPTICAL CONSTANTS OF AMMONIUM SULFATE AND SULFURIC ACID

In the interval since the last report this research has taken on an added task. Additional analysis of upper air aerosol data has led to the belief (Junge, 1965) that the relative proportion of ammonium sulfate in the mid-stratospheric sulfate layer is somewhat less than originally thought. Present indications are that sulfuric acid in the form of a droplet mist is present in significant proportions along with the $(NH_4)_2\ SO_4$ at these levels. It is for this reason that a decision to broaden the present research was made.

A literature search was initiated and carried out to obtain information on the optical constants of sulfuric acid. As in the case of $(NH_4)_2\ SO_4$ some qualitative data are available on the absorption band positions but little or no work has been done in evaluating the optical constants of sulfuric acid. The optical constants (refractive index, n, and absorption coefficient, k) are of basic importance in evaluating the scattering and absorption in a layer containing a given aerosol. The task of this research is to determine the optical constants of the sulfate layer and thus provide research workers with the means of evaluating the contribution of aerosols to their radiation models and also to assess the aerosol's role and influence on satellite measurements of radiation used to sound the atmosphere.

Plans have been made to perform experiments to determine the optical constants of sulfuric acid as well as those of ammonium sulfate. It becomes necessary to design a special sample cell for the sulfuric acid experiments. H_2SO_4 is a strong acid and attacks most common materials. It is not possible therefore to make use of standard liquid cells of stainless steel which are commercially available. A tentative cell has been designed consisting of Teflon as the cell body and BaF_2 or NaCl as the window material. Teflon is excellent in resisting attack by acids and bases and is remarkably inert with respect to H_2SO_4. It is far better in this quality than any other commercially available plastic. The final form of the cell has not been decided upon since consideration of the window material is a factor. While BaF_2 exhibits good transmission characteristics out to about 13.5μ and it is relatively insoluble in water, it displays some solubility in strong acids. There is the possibility of making use of NaCl windows if the sulfuric acid sample can be kept "dry". This possibility is attractive in that NaCl is cheap, a fine transmitter out to about 25μ and although highly water soluble is reportedly rather inert to acids (Handbook of Chemistry and Physics). The relative solubilities of BaF_2 and NaCl in H_2SO_4 will be checked experimentally and the less soluble of the two materials will be used as window material at least for the initial experiments with "dry" sulfuric acid. It will be desirable to make measurements of the optical constants of the hydrates of sulfuric acid also and these may necessitate a more water insoluble window.

The experimental technique used to obtain the optical constants of sulfuric acid will be similar to that already proposed for the study of ammonium sulfate. Basically the two constants (n, k) are obtained by measuring the reflectivity and the transmission of the material at the wavelength in question. The measured transmission yields the constant k, and solving Fresnel's reflectance equation in terms of the reflectivity (R) and k yields the real part (n) of the reflective index.

The equations required to solve for n and k must take into account multi-order reflection effects and transmission effects of window materials, and the solutions tend to be so tedious that it may be desirable to program a computer to do this. Data obtained from the spectrometer experiments are essentially apparent transmission (T) through the sample and apparent near-normal reflectivity (r) of the sample. It can be easily shown that for the solid sample:

$$T = \frac{(1 - R)^2 e^{-\alpha d}}{1 - R^2 e^{-2\alpha d}}$$

and

$$r = R\,(1 + T e^{-\alpha d})$$

where

R = true single surface reflectivity of the sample material
α = wavelength dependent absorption coefficient (L^{-1})
d = sample thickness (L)

Methods of solving for α and R are in the literature (Kahan, 1964) and then n can be calculated from

$$k = \frac{\lambda \alpha}{4\pi}$$

and

$$R = \frac{(n - 1)^2 + k^2}{(n + 1)^2 + k^2}$$

In the case of the liquid sample the expression for the apparent transmission is considerably complicated by the terms contributed by the sandwiching windows, whereas the expression for r reduces to the true reflectivity since the product αd will be made very large.

A special reflectance apparatus for the liquid sample is in the process of design. This will include accessory optics and ventilation to minimize the dangers of acid fumes attacking the reflectance prism and other exposed parts of the monochromator.

References

Handbook of Chemistry and Physics, 1952: Chemical Rubber Publishing Co., Cleveland Ohio.

Junge, C., 1965: Personal communication.

Kahan, A., 1964: On determination of absorption and reflection coefficients. J. Applied Optics, v. 3, n. 2. Letter to the editor.

Richard S. Greenfield

ATMOSPHERIC BREAKING WAVES

The detailed analysis of one of the cases taken from the National Severe Storms Laboratory meso-network was completed during the last period. After carefully considering the data and analysis it was decided that the network does not provide the proper topography to verify the previously determined theoretical results. The topography in the network is essentially a plane upon which there are gentle, low-lying hills. Although there is a reasonably high hill to the west of the network the general topography is unsuitable for two reasons:

1. The slopes are not sufficiently large to have significant effects on a propagating wave.

2. There is not a sufficiently regular slope to approximate the observations by the "inclined plane" model.

At about the time this decision was reached, Dr. Abdul Jabbar Abdullah visited New York University (September 16-17). Dr. Abdullah agreed with the decision and suggested using standard synoptic data in the vicinity of the Rocky or Appalachian Mountains. While Dr. Abdullah was here, a case was discovered in the literature which, it was felt, could be used in the verification attempt.

This case was reported in "Pressure jump sines in Midwestern United States, January-August 1951", U.S.W.B. Research Paper No. 37 by Morris Tepper. Since the case was reported in detail, analytic methods could be applied to compare the theoretical results of the inclined plane model with the observations.

This case involved the formation of a pressure jump (breaking atmospheric wave) on the eastern slope of the Rockies. As Tepper points out in his report:

"An attempt to produce the characteristics diagram suggested by the theory of pressure jumps failed in that it yielded speeds of propagation for the jump line far in excess of the observed. This may in part be explained as due to the terrain."

Tepper was trying to apply a model which had a horizontal, plane lower boundary. He recognized the poor approximation in this case.

Application of the inclined plane results to this case yielded a reasonably good approximation to the observations. The table below indicates the agreement of both the horizontal and inclined plane results with the observations:

	Breaking Time (hours)	Breaking Position (miles)
Observed	5	240
Horizontal Model	3	66
Inclined Plane Model	5.3	155
Modified Inclined Plane Model	5.3	234

Note the close agreement between the "modified inclined plane model" and the "observed". The "observed" results are the position and time of initial detection of the pressure jump. The modified inclined plane results are for the model as originally established but with allowance made for a constant initial motion of the air in advance of the front.

SUMMARY OF PUBLICATIONS AND RESEARCH ACTIVITIES SUPPORTED IN WHOLE OR IN PART BY NASA GRANT NsG-499

The following papers were produced and related research activities were carried out by the faculty and graduate research assistants of the Department of Meteorology and Oceanography, New York University, at the Goddard Institute for Space Studies under Grant NsG-499 from the National Aeronautics and Space Administration, covering the period June 1, 1964 through November 30, 1965.

I. Papers

Fischer, H., 1965: A study of the variation of rate coefficients controlling the chemical reactions in the decaying nocturnal ionosphere between 120 and 240 km (assisted by A. Arking—accepted as Master's thesis, Department of Meteorology and Oceanography, New York University).

Hogan, J.S., 1965: Ozone and carbon dioxide heating in the Martian atmosphere. (with C. Prabhakara), J. of the Atmospheric Sciences, v. 22, pp. 97-109.

Hogan, J.S., 1965: Equilibrium temperature structure in the mesosphere and lower thermosphere (with C. Prabhakara). Goddard Institute for Space Studies, New York.

Levine, J.S., The earth's lower atmosphere, weather and climate. The Reader's Digest Almanac (to be published).

Levine, J.S., The influence of Venus on geomagnetic activity, (to be submitted to the J. of Geophysical Research).

McGovern, W.E., 1965: The rotation period of the planet Mercury (with S.H.Gross and S. I. Rasool), Nature, v. 208, p. 375.

McGovern, W.E., The atmosphere of Mercury (with S.I. Rasool and S.H.Gross) for publication in Space Science Reviews.

Potter, J., supported by the Grant, has been working with A. Arking, and is in the process of preparing his research for publication in the areas of TIROS visible radiation analysis, earth albedo and atmospheric scattering.

Rasool, S.I., 1964: The upper atmosphere of Jupiter (with S.H.Gross), Icarus, v. 3, p. 311.

__________, 1964: Radiation studies from meteorological satellites (with C. Prabhakara). New York University, Geophysical Sciences Laboratory Report No. 65-1.

__________, The atmosphere of Venus. World Book Encyclopedia (to be published).

__________, Planetary atmospheres. Encyclopedia of Earth Sciences (to be published)

__________, Satellite meteorology. Encyclopedia of Earth Sciences (to be published).

__________, 1965: Planetary atmospheres (with R. Jastrow). Chap. 18 in Introduction to Space Science, ed. by Wilmot N. Hess. Gordon and Breach Science Publishers.

Ward, Capt. Arthur D., 1965: Effect of a parabolic shaped mountain on the time and position of breaking of an atmospheric gravity wave (assisted by R. Greenfield -- accepted as Master's thesis, Department of Meteorology and Oceanography, New York University.

II. Meetings, Conferences, and Field Trips

Hogan, J.S., Ozone and carbon dioxide heating in the Martian atmosphere (with C. Prabhakara), presented at International Atmospheric Ozone Symposium sponsored by the Ozone Commission of the International Association of Meteorology and Atmospheric Physics (I.U.G.G.) and by the World Meteorological Organization, Albuquerque, New Mexico, August 31 to September 4, 1964.

__________, Equilibrium temperature distribution in the mesosphere and lower thermosphere (with C. Prabhakara), at 45th Annual Meeting of the American Meteorological Society, New York, N. Y., January 25-28, 1965.

Hogan, J.S. and J.S. Levine participated in the Conference on the Exploration of Mars and Venus sponsored by the National Aeronautics and Space Administration and the Air Force Cambridge Research Laboratory at Virginia Polytechnic Institute, Blacksburg, Virginia, August 23-27, 1965.

Levine, Joel, edited and revised the sections on the solar system and planetary astronomy for the Reader's Digest Almanac, in press.

McGovern, W.E., participated in the Around the World Polar Expedition sponsored by the Rockwell Corp., November 14-16, 1965.

___________, participated in a seven-week Advanced Science Seminar, sponsored by the Department of Meteorology, Florida State University, summer, 1965.

Rasool, S.I., Heat balance of the atmosphere and oceans (with C. Prabhakara), presented at the International Symposium on Radiation sponsored by I.U.G.G., held in Leningrad, August 5-12, 1964.

__________, Theoretical calculations of an atmosphere of Mercury, presented at the Fourth Western Meeting of the American Geophysical Union held in Seattle, Washington, December 28-30, 1964.

James E. Miller
Principal Investigator

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